Characterization of Atmospheric Mineral Dust from Radiometric and Polarimetric Remote Sensing

PI: Prof. Irina N. Sokolik
School Of Erath and Atmospheric Sciences
Georgia Institute of Technology
311 Ferst Dr., Atlanta, GA, 30332
Phone: 404-894-6180 fax: 404-894-5636 e-mail: isokolik@eas.gatech.edu

Grant number: N00014-0410429
http://irina.eas.gatech.edu

LONG-TERM GOALS

The overall goal is to improve an understanding of the properties of mineral aerosols and their interactions with visible and IR atmospheric radiation, and to develop the dust optical models needed for new satellite radiometric and polarimetric sensors proposed for the NPOESS and other satellite missions.

OBJECTIVES

The main objectives of this research program are as follows:

1) develop advanced optical models of mineral dust required for the new generation of multi-channel, multi-angle remote sensors operating in the visible to IR spectral ranges;

2) develop robust techniques for discriminating dust from clouds and evaluate the contamination of aerosol signal by cloud scattering;

3) investigate the capability of polarimetric remote sensing to quantify dust microphysical and optical properties.

APPROACH

Our approach combines an extensive forward modeling, analysis of laboratory and in-situ data of dust microphysical, optical, and radiative properties, analysis of remotely sensed data from currently operating satellite sensors (such as MODIS, MISR and AIRS) as well as ground-based polarization measurements in the urban and dust-laden conditions.

WORK COMPLETED

1) Using MODIS Terra Level 1B data containing calibrated and geolocated radiances, we investigated a regional signal of wind-blown mineral dust over the oceans. The goal of this study was to identify the thermal-IR radiative signature of atmospheric dust originating from the main world's dust production regions and explore the implications to the dust detection over oceans with the techniques based on brightness temperature differences. For the 2000-2004 time period, MODIS data were examined for

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Characterization of Atmospheric Mineral Dust from Radiometric and Polarimetric Remote Sensing**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Georgia Institute of Technology,School Of Erath and Atmospheric Sciences,311 Ferst Dr,Atlanta,GA,30332**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The overall goal is to improve an understanding of the properties of mineral aerosols and their interactions with visible and IR atmospheric radiation, and to develop the dust optical models needed for new satellite radiometric and polarimetric sensors proposed for the NPOESS and other satellite missions.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

the presence of dust plumes originating from the dust sources located in East and South Asia, Middle East, Northern Africa, and Australia. A number of representative cases for different source regions were selected and analyzed in terms of brightness temperatures at three MODIS IR channels centered at 8.55, 11.03, and 12.02 μm. Several techniques proposed for detecting mineral dust using thermal-infrared observations (such as the split-window method and trispectral methods) were tested on a case-by-case basis. Our analysis revealed several drawbacks in these methods. The work is currently underway to develop a new robust method for the discrimination of dust from clouds by combining solar and thermal IR channels. The results of this study were presented at several scientific meetings (Darmenov and Sokolik, 2004, 2005) and published in the peer-reviewed journals (Darmenova et al., 2005; Darmenov and Sokolik, 2005).

2) We have been working on the development of a one-dimensional radiative transfer model with polarization capable of computing the Stokes parameters taking into account multiple scattering and absorption of aerosol particles in multi-layered aerosol conditions. The layers can have different aerosol external and/or internal mixtures consisting of various individual species. The model was used to perform a sensitivity study to explore the extent to which the degree of linear polarization is affected by absorbing aerosols. The modeling results were analyzed in conjunction with polarimetric observations. Measurements were carried out in the Atlanta Metropolitan Area using a CIMEL sun-sky photometer with a polarimetric channel in conjunction with a suite of in-situ aerosol instruments including a Magee Scientific Aethalometer, Particle Soot Absorption Photometer, Nephelometer, and an EC/OC instrument. Several techniques to retrieve the single scattering albedo were tested. The results will be presented at the Fall AGU (Karpowicz and Sokolik, 2005) and American Meteorological Society meetings (Karpowicz et al., 2006).

3) Under previous ONR support, we developed a new technique to model optical characteristics of non-spherical dust particles (Kalashnikova and Sokolik, 2002, 2004). The method combines dust particle composition-shape-size (CSS) distributions reconstructed from the electron microscopy data, effective medium approximations and discrete dipole approximation (DDA) method. We applied this technique to the data from the PRIDE and ACE-Asia experiments, and a set of optical models for Asian and Saharan dust analogs were developed. The dust models were tested using satellite Multi-Angle Imaging radiometer (MISR) data (Kalashnikova et al., 2005), resulting in successful retrievals of aerosol optical depth of the dust plumes over the ocean while Mie dust optics failed to retrieve dust. This approach was further refined by incorporating new data that has become available on physiochemical properties of dust samples representative of two dust production regions in the Sahel and China. The focus was on a better understanding of the nature of light absorption by dust. The results of this work were reported by Lafon et al. (2004, 2005).

RESULTS

1) Based on the analysis of four years of MODIS Terra Level 1B geolocated radiances in IR channels, we found the distinct regional radiative signatures of atmospheric dust. This regional radiative signature is likely due to the different mineralogical composition controlled by the diverse dust sources, although the multilayered vertical distribution may also be important. Thus, one has to consider the origin of atmospheric dust in order to utilize the brightness temperature difference techniques in their full potential. In turn, the regional IR signature may be helpful in identifying the origin of dust plumes from remote sensing observations. A combination of passive IR remote sensing and the space lidar CALIPSO has a high potential to provide an additional constraint on dust regional

properties. We also found that the MODIS cloud mask failed to differentiate between dusty and cloudy pixels. Dust was mistakenly identified as clouds in many circumstances. Our analysis demonstrated that discrimination between cloudy and dusty pixels based on the split-window approach or the trispectral approach is not reliable. Further development of these techniques (e.g., taking into account regional differences in brightness temperature in the presence of dust) will be required.

2) A forward radiative transfer model with polarization has been developed which accounts for multiple scattering and light absorption by aerosol particles. The model and ground-based polarization observations were used to explore the extent to which the degree of linear polarization is affected by absorbing aerosols of varying concentration, composition, and mixing state. Our study provided some evidence that polarization measurements have the potential in improving retrievals of microphysical properties of light absorbing aerosols such as dust and black carbon. We found that the degree of internal or external mixing can significantly change linear polarization. Opposite trends were found for increasing amounts of absorbing species for an external mixture compared with increasing amounts of absorbing species coated with water soluble non-absorbing aerosols. This phenomenon could help to explain the trends observed in the CIMEL sun-sky photometer data. We also found that the degree of linear polarization is very sensitive to the total number concentration (via aerosol optical depth). This is clear from both our modeling studies and from the CIMEL sun-sky photometer data. However, retrievals of the aerosol optical depth based on the degree of linear polarization alone would not be possible since there are other parameters which clearly influence the polarization measurements. Our study suggests that to fully benefit from polarization measurements they will need to be conducted with a suite of other radiation and/or aerosol measurements. Development of such an observational system along with new aerosol retrieval techniques will be the focus of our study in FY2006.

3) We used new data on the amount of iron oxides in Asian and North African dust to address the ability of dust to absorb light in the visible region. We showed that the aggregates of iron oxides and clays, which are a key light absorbing species of mineral dust, can have the effective refractive index in a range from about 3.8×10^{-5} (for "pure" kaolinite) to about 4.6×10^{-3} (for aggregates with 2% hematite) at 550 nm. This variability is mainly due to variations in source-dependent "free" iron content, and iron oxides and clay mineralogical speciation (Lafon et al., 2005). Given that dust mixtures consist of the iron oxide-clay aggregates as well as several other minerals (e.g., quartz, calcite) which do not absorb light in the visible, the effective absorption of dust is expected to be even lower. The single scattering albedo of Asian and Sahel dust predicted with new values of the free-iron content are higher than those previously attributed to those dust types.

IMPACT/APPLICATIONS

New techniques and the models of the regional optical properties of dust developed under this grant can be employed in various remote sensing. Our models were incorporated into a MISR retrieval algorithm.

TRANSITIONS

Our main results were published in peer-reviewed journals and presented at numerous scientific meetings.

RELATED PROJECTS

We have been working on developing the non-spherical dust models for the space lidar CALIPSO. Our work on both projects has the high potential to provide a framework for the development of the new generation of aerosol models required for both passive and active remote sensing from the UV to the IR.

PUBLICATIONS in FY2005

Darmenov A., and I.N. Sokolik, Identifying the regional thermal-IR radiative signature of mineral dust with MODIS, *Geophys. Res. Lett.*, 32, L16803*, doi:*10.1029/2005GL023092, 2005 [published, refereed]

Darmenov, A., and I.N. Sokolik, Discrimination of mineral aerosols from clouds with passive multi-channel space-borne sensors. EOS Trans. AGU, Fall Meeting, Suppl. 2005 [published, refereed]

Darmenova K., I.N. Sokolik, and A. Darmenov**,** Characterization of East Asian dust outbreaks in Spring of 2001 using ground-based and satellite data*. J. Geophys. Res.*, doi: 10.1029/ 2004JD004842, 2005 [published, refereed]

Hong, G., P. Yang, H.L. Huang, S. Ackerman, and I.N. Sokolik, High-resolution infrared spectral signature of overlapping cirrus clouds and mineral dust, *Geophys. Res. Lett*., 2005 [submitted, refereed]

Kalashnikova, O., R. Kahn, I.N. Sokolik, and W.-H. Li, The ability of multi-angle remote sensing observations to identify and distinguish mineral dust types: Part 1. Optical models and retrievals of optically thick plumes. *J. Geophys. Res*., 110, D18S14, doi:10.1029/2004JD004550, 2005 [published, refereed]

Karpowicz, B., and I.N. Sokolik, Exploring the potential of polarimetric measurements in studies of light absorbing aerosols. EOS Trans. AGU, Fall Meeting, Suppl. 2005 [published, refereed]

Karpowicz, B., I.N. Sokolik , R. J. Greenwald, R. Peltier, R. J. Weber, and M. H. Bergin, Photopolarimetric measurements in the Atlanta Metropolitan Area, and their potential for improving characterization of absorbing aerosols. 86th AMS Annual Meeting, 29 Jan.-2 Feb., Atlanta, GA, 2006. 2006 [published, refereed]

Lafon S., J.L. Rajot, Sokolik I.N., S. Caquineau, S., S.C. Alfaro, P. Formenti, M. Maille, and A. Gaudichet, Comprehensive Characterization of Size-resolved Composition and Morphology of Mineral Dust Particles for Radiative Forcing Studies. EOS Trans. AGU, Fall Meeting, Suppl. 2004 [published, refereed]

Lafon, S., Sokolik, I. N., Darmenov A., Legrand, M., Rajot, J. L., and Gaudichet, A., Sensitivity of IR radiative properties of dust aerosols to their mineralogical composition: implications for IR remote sensing. EOS Trans. AGU, Fall Meeting, Suppl. 2005 [published, refereed]

Lafon S., I.N. Sokolik, S. Caquineau, S., J.L. Rajot, and A. Gaudichet, Characterisation of iron oxides: implications to light absorption by mineral dust aerosols. *J. Geophys. Res.*, 2005 [submitted, refereed]

Miecznik G., R. Illing, S. Petroy, and I.N. Sokolik, Retrievals of aerosol properties from multi-angular and multi-spectral polarized radiances: Sensitivity study. *Applied Optics*, 44, 4186-4204, 2005 [published, refereed]

Sokolik I.N., Emerging challenges in studies of dust impacts on the climate system. 4th ADEC Workshop (Aeolian Dust Experiment and Climate Impact), 26-28 Jan., Nagasaki, Japan, 2005 [published, refereed]